needs a bit more work...

0.0.1 Phenomena related to thermal contrasts

Regional-scale thermal contrasts might drive mesoscale circulations. Because of the aforementioned strong radiative forcing, such circulations develop close to the surface where regional contrasts of surface temperature might develop, related to contrasts in soil thermophysical properties (thermal inertia, albedo). This is the Martian analog to land/sea breezes circulations on Earth. It is related to the hypsometric equation which combines hydrostatic equilibrium with ideal gaz law

$$\frac{\mathrm{d}p}{p} = -\frac{\mathrm{d}z}{H} \quad \text{with} \quad H = \frac{RT}{g} \tag{1}$$

which shows that the thickness of an air layer enclosed within two isobars is greater within a warmer layer than within a cold layer. For instance, consider an area where the albedo is high close to an area where the albedo is low : during daytime, the surface and the atmosphere aloft in the former area is cooler than in the latter area. A few kilometers above the surface, this yields an horizontal pressure gradient, which causes winds to blow from the warm region to the cold region, then surface pressure increases in the cold region, which cause a reverse circulation near the surface. This kind of circulations are named thermally-induced winds.

The most prominent of such circulations on Mars are circulations close to the caps. It has been a preferential topic for mesoscale modelers because those strong winds trigger near-cap dust storms. This phenomena was quantified by Toigo et al. [2002] (for southern polar regions) in order to complement the numerous observations on board Mars Global Surveyor [Cantor et al., 2006], which showed that dust lifted at the edge of polar caps play a significant role in the whole Martian dust cycle and the annual dust budget. Mesoscale models are necessary to resolve such thermally-induced circulations because thermal contrasts between icy caps and bare soil extend over a few tens of kilometers with a sharp boundary – in addition to that, the mesoscale model is able to take into account the combined effect of contrasts in topography and soiol thermophysical properties close to the cap edge. Another advantage of mesoscale models is that those are devoid of any pole singularity, contrary to GCMs, which makes them helpful tools especially for polar regions. This advantage of mesoscale models on GCMs is further confirmed by simulation results. One problem with GCMs was that winds on the edge of the caps were predicted to be very low at southern spring, while observations indicate that at this season the cap storm activity is at his peak. This is better reproduced through mesoscale modeling which shows wind stress compatible with possible dust lifting at the edge of the cap. In addition to that, Toigo et al. [2002] were able to show that it is the thermal contrast between the polar cap covered with CO_2 ice with the bare soil at lower latitudes that is the main driver of the strong near-surface winds likely to cause dust lifting at caps'edge. The influence of topography (through slope winds, see previous subsection) is significant but less than thermally-induced winds. The influence of large-scale condensation flow is found to be weak, but acts to reinforce a little bit mesoscale winds. A similar conclusion was reached earlier through idealized 2D experiments by Siili et al. [1999].

Dust storms at the caps'edge are one of the numerous mesoscale phenomena extensively observed by instruments on board the Mars Global Surveyor Mission. Another key mesoscale phenomena associated to thermal contrasts are fronts, sometimes spectacularly associated to hemispheric dust lifting [Wang et al., 2003]. Fronts are defined as mesoscale circulations associated to thermal contrasts particularly localized. Those are usually associated in mid-latitudes to baroclinic wave activity; hence an horizontal pressure gradient is associated to the thermal contrast. This has been supposedly observed through mapping surface pressure with the OMEGA spectrometer on board Mars Express, using the 2 μm CO_2 absorption band: a 10 Pa gradient over a couple of hundreds of kilometers in the mid-latitudes is supposed to be associated to frontal activity. Thus far frontal activity have not been addressed through Martian mesoscale modeling; fronts were considered as part of baroclinic wave activity, which has been extensively studied using observations and GCMs [Barnes et al., 1993, see also chapter **??**]. It is a likely area of future research for mesoscale modelers.

Circulations associated to thermal gradients were also described by Tyler and Barnes [2005] and named transient eddies. Those are circulations specific to polar regions. Tyler and Barnes [2005] focussed on polar mesoscale circulations at the northern polar cap in summer, which receives at this season maximum and permanent incoming solar radiation. It is important to address the mesoscale motions at this very season and region because this where and when the release of water vapor from the cap is maximum, of key importance to study the water cycle. Tyler and Barnes [2005] found evidence in their simulation of forming transient eddies during summer, where near-surface wind perturbations could reach 10 to 15 m s^{-1} close to the surface. In the surface pressure signal, they found structures with zonal wavenumber of amplitude $1 - 1.5\%$. Circulations are confined within one scale height above the surface. Such perturbations are supposed to be excited through strong slope winds close to the surface. At the end of summer, the influence of baroclinic waves is stronger and overcome the transient eddies with pressure departures of about 2%.

0.1 Mesoscale waves

Gravity waves (hereafter GWs) are mesoscale atmospheric oscillations related to the buoyancy restoring force, which play a key role in the circulation, structure and variability of planetary atmospheres [a review on terrestrial knowledge on this topic can be found in Fritts and Alexander, 2003]. On Earth, vertically-propagating GWs originate in the lower part of the atmosphere by a variety of mechanisms involving topography, fronts, convective cells, jet-streams, wind shears and wave-wave interactions [Fritts et al., 2006, Spiga et al., 2008, and references therein]. In the 1970s, Mariner 9 and Viking missions revealed that GWs are ubiquitous in the Martian low-density stable atmosphere too Briggs and Leovy [1974], Pirraglia [1976], Pickersgill and Hunt [1979]. The crucial role of GWs in transporting energy and momentum and influencing the synoptic circulation and thermal structure has been acknowledged in both planets [see e.g. Mars Global Circulation Modeling by Wilson, 1997, Forget et al., 1999]. Typical horizontal scales of such phenomena range from thousands of kilometres to few kilometres.

Since their propagation produces both fluctuations in the temperature and

density fields, Martian GWs have been identified from orbit in thermal profiles derived both by infrared spectrometry and, mostly, radio occultation [Hinson et al., 1999, Creasey et al., 2006], in density measurements obtained by accelerometers during the aerobraking phases of Mars Global Surveyor (MGS) and Mars Odyssey (ODY) spacecrafts [Keating et al., 1998, Creasey et al., 2006, Fritts et al., 2006] and by MGS Mars Orbiter Laser Altimeter (MOLA) anomalies caused by CO2 ice wave clouds in the polar night [Pettengill and Ford, 2000, Tobie et al., 2003]. The propagation and/or breaking of those waves yield local temperature and momentum disturbances at altitudes above ~ 60 km [detected in entry profiles, e.g. Magalhaes et al., 1999, Withers and Catling, 2010]; mixing layers in the upper part of the Martian atmosphere were detected in Mars Climate Sounder profiles and attributed to GWs [Heavens et al., 2010]. Apart from cloud imagery by the Mariner and Viking spacecrafts [Pettengill and Ford, 2000], Martian GWs were seldom mapped, except perhaps for dayglow emission measured on board Mars Express which is suspected to have captured oscillations caused by gravity waves Spiga et al. [2007], Altieri et al. [2009], as it is often observed on Earth [Melo et al., 2006]. Gravity waves are through to be closely related to the formation of water ice clouds close to topographical obstacles [Michaels et al., 2006] and, even, the high-altitude CO_2 clouds [Spiga et al., 2011].

add more quantitative estimates.

The topographical source was mostly discussed in Martian studies but other sources do exist on Mars – which is actually emphasized by results of Creasey et al. [2006]. Mars is characterized by powerful convection in the troposphere, both related to boundary-layer turbulence and local dust "storms". Near-surface superadiabatic gradients cause intense daytime boundary layer convection, with turbulent updrafts reaching 10 km above local surface. The stably stratified free atmosphere above the convective boundary layer is perturbed by those updrafts, which gives rise to internal GW Spiga and Forget [2009]. Besides, deep "convective" motions could develop inside regional dust lifting (sometimes several tens of kilometres wide). Dust locally warms the atmosphere, which triggers thermal circulation; strong updrafts within the dusty column could generate GW. Characteristics and sources of GWs remain, however, to be further assessed on Mars, both through original observational methods and mesoscale modelling (where part of the GW spectra is resolved and not parameterized). Martian studies could be of interest in GW meteorology in general, by providing original examples of these phenomena in an extra-terrestrial environment.

add a concluding about strong nonlinearity expected close to giant mountains on Mars and perhaps something about trapped waves

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